4.9 Integrity of Analyses

4.9.1 Introduction to Integrity to Analyses

Analysis is defined as a logical examination or study of a system to determine the nature, relationships, and interaction of its parts and environment. Analysis emphasizes baseline system performance and/or compares development, production, or usage alternatives. Analysis is performed throughout the entire product lifecycle to support program decisions, encompassing technical performance and system acquisition considerations. Specific analyses are used throughout the System Engineering (SE) process. Analyses conducted to support a program may only add value if the results are credible, useful, and sufficient.

Analysis, as described here, encompasses a broad range of perspectives. The nature of the system dictates that analysis may be performed relative to the entire system (or its subsets), the system's interaction with other systems, and/or the environment in which the system operates. Analysis may focus on the operational, functional, or physical aspects of the system and its interfaces. Analyses may range from the simple to the complex, quantitative to qualitative, top-down to bottom-up, and basic formulas to sophisticated simulations. Some specific scenarios that require analyses include:

- Exploring system concepts regarding viability and technology maturity
- Determining operational system requirements and measures of system merit
- Determining key system performance relationships to cost and other acquisition parameters
- Evaluating key system quality factors, including reliability, readiness, and maintainability
- Evaluating potential changes to improve performance, reduce cost, etc.
- Assessing risks and potential risk mitigation options
- Synthesizing allocated requirements into an acceptable physical design
- Evaluating specific physical designs (components and interfaces)
- Determining system characteristics before building or integrating the system
- Verifying system, subsystem, and component performance at various stages
- Monitoring production quality
- Diagnosing observed or perceived system deficiencies
- Evaluating produced and fielded system performance
- Evaluating processes used to support and achieve results

To ensure credible, useful, and sufficient data/results for program management's decision-making process, the integrity and fidelity of various analyses performed on a program shall be understood and validated. This validation takes several forms**:** through the attributes of the tool suite (Paragraph 4.9.3.2), the proficiency and skills of the analyst (Paragraph 4.9.3.3), and the validity of the input data (Paragraph 4.9.3.4). The actual analyses performed are described in the other sections of this manual. The Integrity of Analysis process supports the other SE processes and is intended to provide a disciplined framework for conducting any required analysis, whether technical, programmatic, or administrative in nature. An Analysis Management Plan (AMP) that outlines the details of the various analysis methods and tools is either generated or incorporated into the Integrated Program Plan (IPP). It is recommended that this planning effort reflect the available inputs and program constraints regarding technical capabilities, schedule requirements, and cost requirements.

A wide range of tools may support analysis, including a spacecraft facility, wind tunnel, manned aircraft simulator, iron bird, computational model, physical model, computer-aided design model, spreadsheet, photograph, or paper and pencil. The analysis methods used, including tools, shall provide the required level of fidelity in representing the system or subsystem and any associated interfaces. The selected analysis method may be quantitative or qualitative, or both. The common feature of all tools is that the tools are approximations of the system being analyzed. The level of fidelity achieved is one of the primary features that often sets one tool apart from another tool.

Integrity of Analyses is defined as a disciplined process applied throughout a program to ensure that analyses provide the required levels of fidelity, accuracy, and confirmed results in a timely manner. Competent users who iteratively apply a validated set of tools to a clearly defined data set ensure integrity. The Integrity of Analyses process (Figure 4.9-1) identifies the following tasks that shall be performed to ensure integrity:

- For each analysis, identify objectives, level of detail, and degree of validation required

- Select and/or develop the tools to meet the identified needs

- Ensure availability of analysts proficient in using the selected tools

- Ensure availability of proper and correct input data for each analysis conducted

- Perform analysis (reference task; see the SE element performing the actual analysis)

- Verify that analysis results are correct, useful, and sufficient

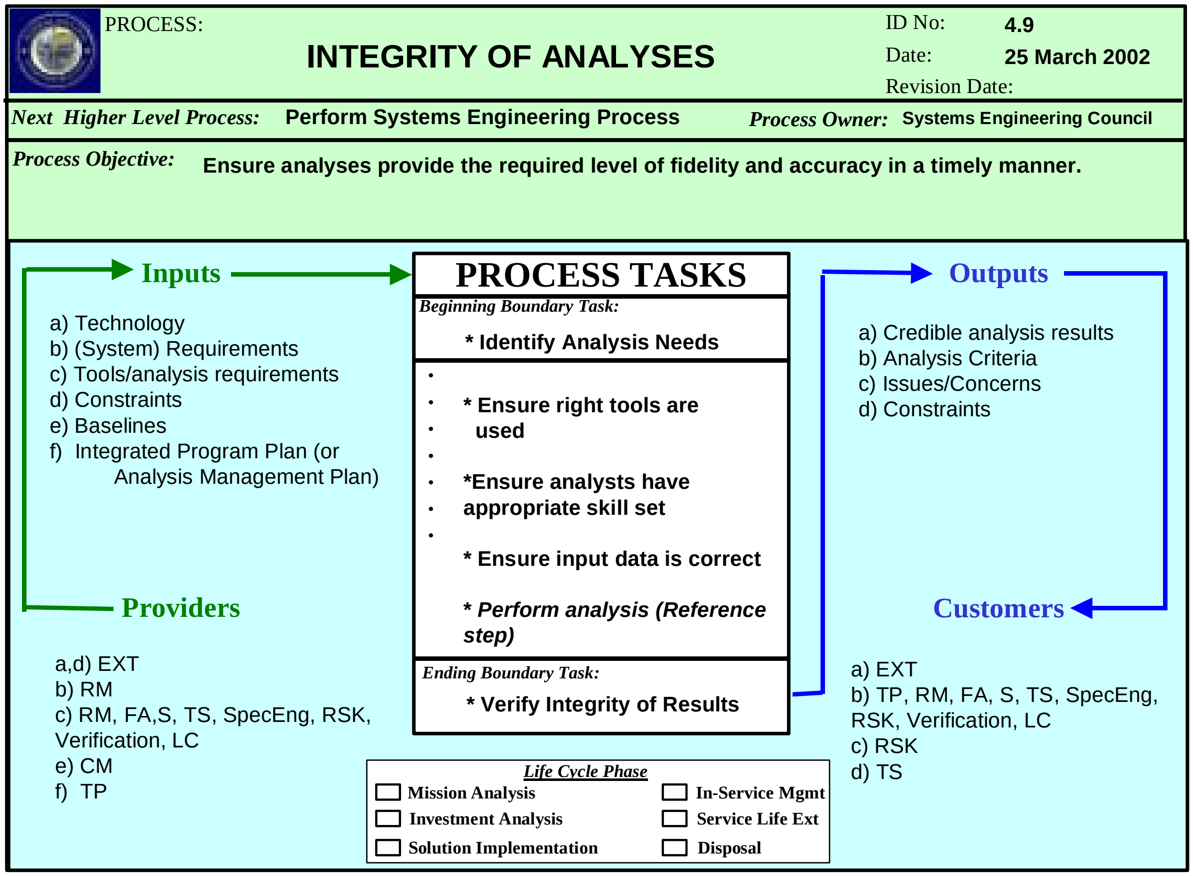

Figure 4.9-1 Integrity of Analyses Process-Based Management Chart

4.9.1.1 Purpose

The Integrity of Analyses process provides systematic guidance that leads to analysis results, including the following:

- **Credible.** Results are valid and their implementation is feasible.
- **Useful.** Results align to their intended use in the program decisionmaking process.
- **Appropriate**. Quantity and quality are sufficient to properly aid decisionmaking without performing excessive analysis.
- **Verifiable**. Results are accompanied by a methodology, rationale, and traceability that produce an appropriate confidence level in the results.

Executing the process tasks identified in Figure 4.9-1 results in selecting the required analysis methods, performing the analysis, and verifying the results.

The initial selection of the method, tools, or model to be used in an analysis focuses on finding a practical tool that provides the most visibility into the problem with the least complexity. The process is implicitly iterative and is used across the program throughout its lifecycle. Because the process is iterative, there is an ongoing need to use the best approach to select the right method, tool, or model, considering the preferences of the stakeholders and other teams' previous experience with different tools. In addition, the limitations of budgets, technology, and schedule shall be evaluated. The bottom line is to have analyses in place that guard against mistakes and embed a consistent level of confidence in the integrity of the analysis. The analysis, in turn, contributes significantly to the success of the decisionmaking processes of program management, teams, stakeholders, and contract managers. This result is achieved by addressing the methods of analysis to be used, attributes of the toolset, quality of the workmanship, and validity of the input data. The following paragraphs define the tasks that need to be completed to achieve analysis with integrity. Figure 4.9-2 illustrates the process tasks as well as the interactions between the Integrity of Analyses process with other SE elements.

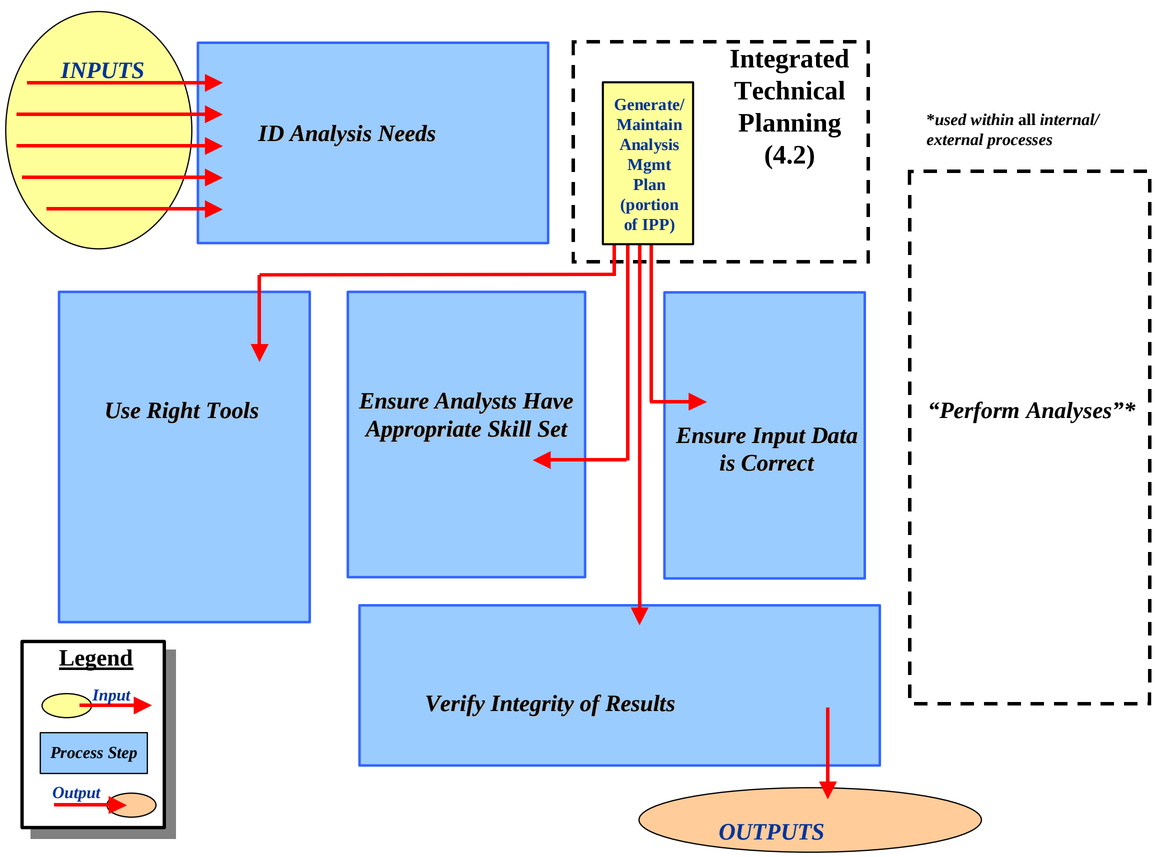

Figure 4.9-2. Integrity of Analyses Process

4.9.2 Inputs to Integrity of Analyses

Technology. Technology insertion determines the methods and tools employed for various analyses. The degree of technology insertion is driven by schedule and economic factors.

(System) Requirements. These requirements are defined to the extent that the results of a given analysis support a programmatic decision, whether driven by technical, cost, or schedule.

The requirements are generated from customer, internal, or supplier sources and may be expressed textually or as models.

Tools/Analysis Requirements. The various process elements discussed in Integrated Technical Planning (Section 4.2) that perform analyses provide the requirements for tools and analysis for the project, which are constrained by program technical, schedule, and cost requirements and plans imposed by project management. These requirements are typically reflected in the planning information developed under Integrated Technical Planning.

Constraints. The analysis needs are frequently a balance between the desires and costs of analytic excellence (usually championed by the analysts) and the program's cost/risk/benefit constraints, which are usually reflected in the program's budgets, schedules, and goals.

Baselines. This data set defines the aspect of the system being modeled or analyzed, and is under configuration control to the extent that all elements of the program are using the same baseline.

IPP. As part of the IPP or as a stand-alone plan, the AMP contains the planning effort for the right tools, data, and analyst skill set. The AMP is developed and maintained under the Integrated Technical Planning process (Section 4.2).

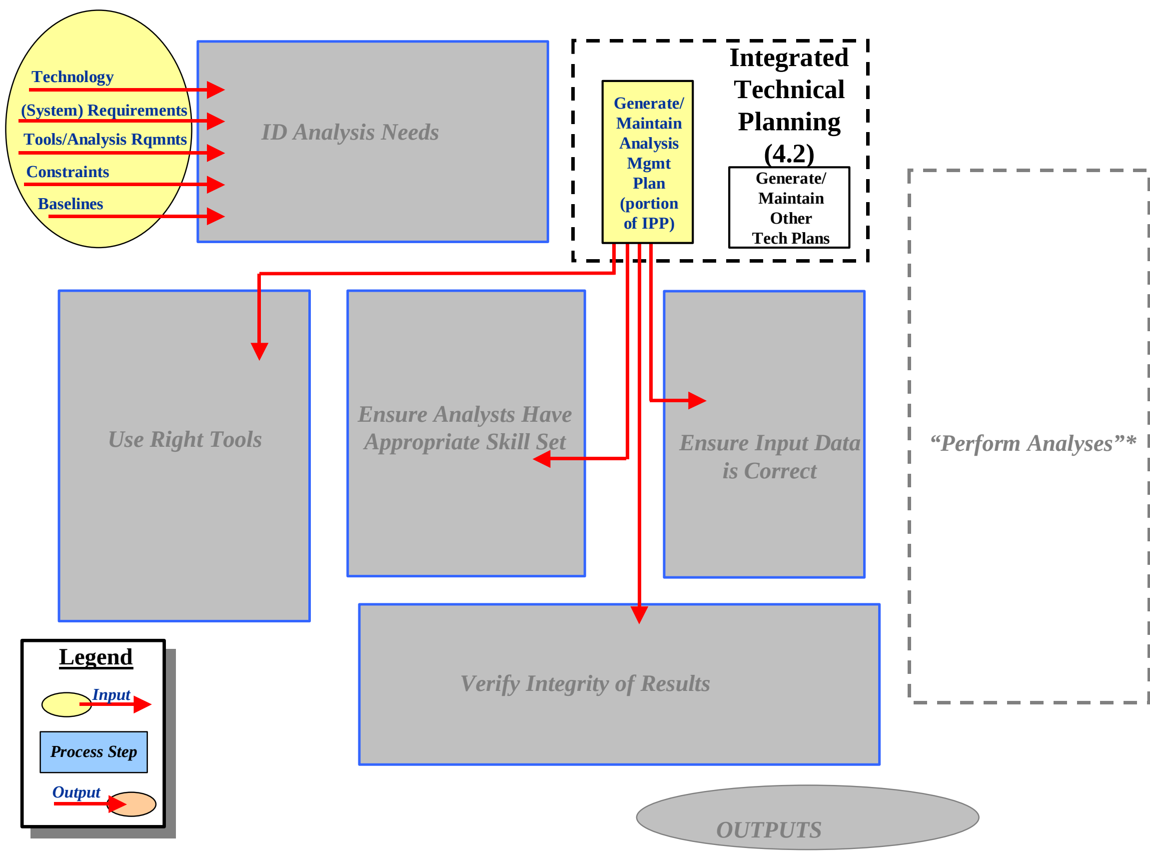

Figure 4.9-3. Integrity of Analyses Process Inputs

4.9.3 Integrity of Analyses Process Tasks

4.9.3.1 Task 1: Identify Analysis Needs

As indicated by the definition in the introduction of this section, analysis is used to investigate system structure or behavior. The analysis results form a decision aid that emphasizes certain aspects of system structure or performance in a limited number of architectures or configurations. Analyses are performed for a variety of specific needs relative to the system's lifecycle. For an analysis to be truly effective, the analysis results shall be closely aligned with the expressed needs and the decisions that the analysis is designed to support. It is good engineering practice to identify and plan around these needs. It is recommended that specific analysis needs be identified in the following areas:

- **Understand the various perspective(s)** to aid in decisionmaking (e.g., system users, acquirers, builders, testers, and suppliers). Analysis results shall address stakeholder requirements and be capable of undergoing translation to address different stakeholder perspectives.

- **Codify objectives, requirements, and constraints** for the analysis itself and for managing the analysis. This includes using appropriate case definition and acceptable analysis products, as well as criteria that ensure suitability and effectiveness of the analysis when the analysis is complete. It is recommended that a concerted effort be made to identify which requirements are firm or soft and what conditions enable change.

- **Obtain sufficient system and environmental definition** to conduct the analysis cases. This includes defining analysis boundaries, necessary assumptions, rationale, frequency and depth of analysis, interactions required with other analyses, and capabilities of the toolset.

- **Identify control and decision points** to manage analysis methods and tools effectively. Established exit criteria for each phase of analysis are useful.

- **Understand data flow and organization needs** associated with the analysis.

The Integrity of Analysis process tasks appear in Figure 4.9-4. Once the needs are understood clearly and addressed, the foundation is laid for managing the analysis set to obtain the needed results, which then serve as the basis to generate the AMP, as described in Integrated Technical Planning (Section 4.2).

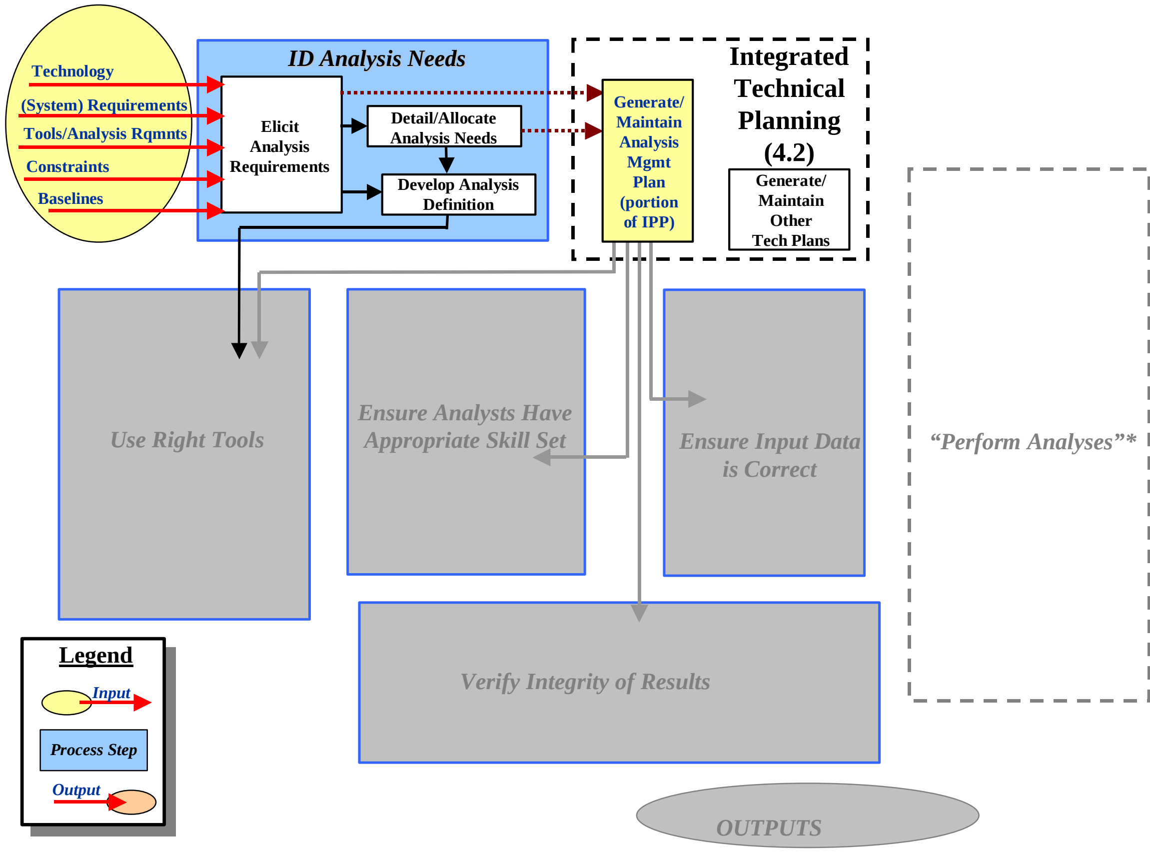

Figure 4.9-4. Identify Analysis Needs

Early analysis planning is key to program success. The quality of the analysis effort across the program is augmented by developing the program's AMP, a living document that manages and controls program analysis activities. The plan typically begins with a clear statement of project management goals, philosophies, and policies, followed by data to support planning for the analyses to be performed. The analysis needs are frequently a balance between the desires and costs of analytic excellence (usually championed by the analysts) and the cost/risk/benefit constraints of the program's budgets, schedules, and goals.

The AMP identifies required levels of analysis and the data to perform an analysis, defines procedures for ensuring analyst competency, contains details on the subset of analysis methods and tools that may be used for a validated analysis, and defines the criteria to ensure integrity of the analysis results. The AMP provides specific tailoring required by the project. The plan provides specific tailoring required by the project and is updated when a new tool is validated on the program or when a currently validated tool is updated to reflect a change in the product design and is subsequently revalidated. Because new methods and tools may be needed for product variants, and because multiple versions of a product may exist concurrently, the AMP may contain reference to multiple validated versions of the same tool.

4.9.3.2 Task 2: Ensure the Right Tools Are Used

Developing meaningful system performance and cost estimates, establishing the associated system performance and design requirements, and defining acceptable tolerances may be accomplished only if analyses and performance models/databases are well defined and controlled and demonstrate validity. In addition, it is essential that analysis tool/model changes, updates, and predicted performance variances are properly identified and tracked over time. Independent but related tools/models and simulations also be validated by comparison with a single reference baseline to ensure consistency of results.

An excellent and frequently stated guideline for choosing a tool/model is to select one that provides the most visibility into the problem but has the least complexity. It is recommended that practical tools/models include only features that are necessary for exploring the interactions between the study, object system, and its environment. There are many inhibitors to applying this guideline. Familiarity with a tool or a model often biases use of the tool. Lack of familiarity, inadequate training, or a "not invented here" syndrome may cause analysts to avoid a tool. The customer may expressly require use of a particular simulation tool or model. Management may demand that a single model be used throughout the program's life. A sound SE approach to select the right tool may overcome a number of these inhibitors. To ensure the proper selection of a tool, it is recommended that the requirements of the analysis be considered, including:

- Analysis objectives
- Required level of fidelity and accuracy
- Cost controls
- Schedule constraints
- Need for additional resources

Analysis needs are allocated to tool components. Allocation includes assessing the level of fidelity required for each study function. For example, one study may require high fidelity if thrust, fuel flow, and range are being assessed, but lower fidelity in target selection. Tools that satisfy the functions and allocated study requirements for the model may be selected from

existing tools, modifications to existing tools, or by the creation of new tools (Identify Candidate Tools task). Each tool shall be examined to verify its ability to meet the analysis needs of the project before it is selected for use. Existing tools may not provide the functionality needed for the analysis. Under these circumstances, the project is faced with modifying an available commercial-off-the-shelf product, developing a proprietary tool for that application, or reconsidering the analysis scope. This evaluation shall be performed periodically to ensure the tools continue to satisfy current project requirements. In addition, analysis shall be performed to assess the availability of new technology in tools, as it becomes available, and determine when it is prudent to switch to the newer technology, factoring in the costs of migration in terms of people, time, and money. The considerations for selecting the right tool(s) appear in Figure 4.9-5 and discussed in detail below.

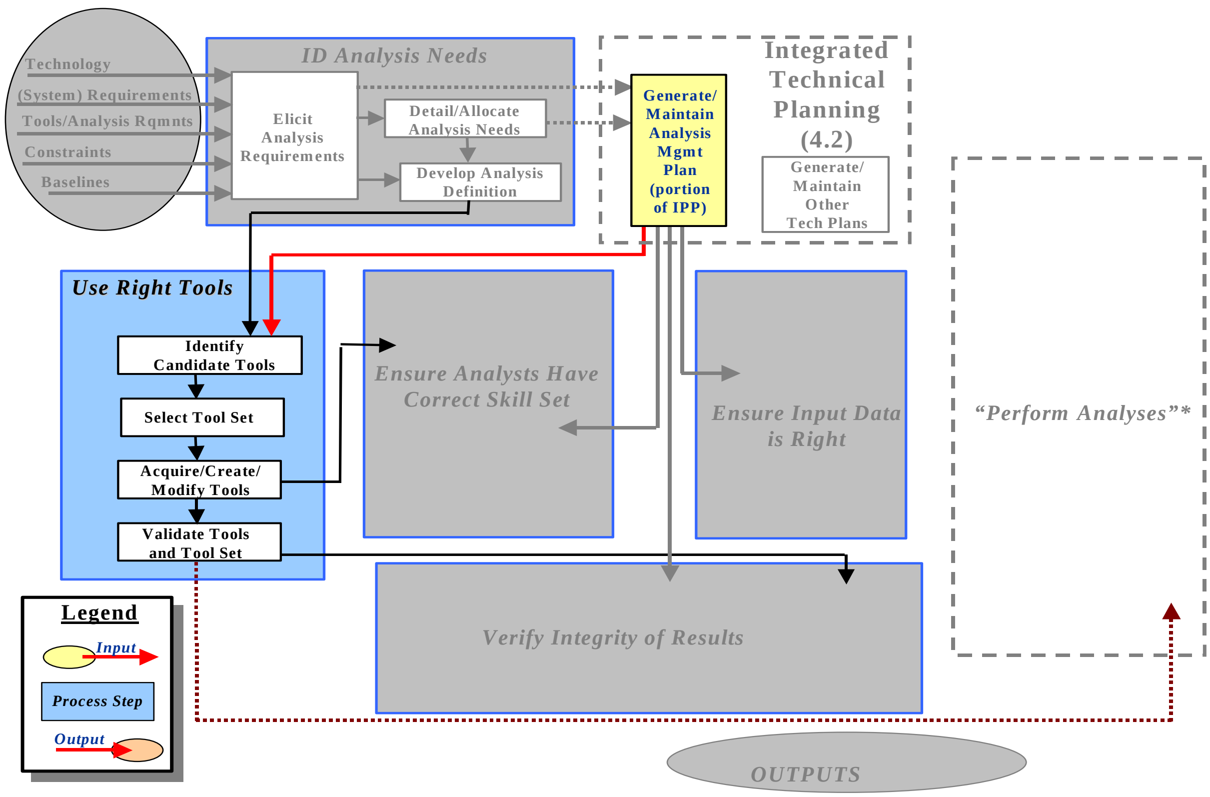

Figure 4.9-5. Use the Right Tools

4.9.3.2.1 Tool Fidelity

One of the more confusing aspects of proper model selection is fidelity. High fidelity and high visibility into cause and effect are usually contradictory goals for a tool. As fidelity increases, basic top-level interactions and characteristics become obscured, which is particularly true of tools that incorporate random choices. Even in totally deterministic tools, the decision logic may become so complex that the visibility is lost. Occasionally, high fidelity may block goal achievement. High-fidelity tools often provide more than is realized and analysts remain blissfully unaware of the true causes of model results.

For practical reasons, such as cost and schedule, the best choice is to use the least fidelity possible, but a model that still includes the desired effects. One shall constantly look for interactions between system components and the environment that require modeling at a higher fidelity. If the system under study includes a human decision process, then one of the best places to determine such interactions is by talking to people who operate the real system to determine what things they attempt to use to their advantage or what they attempt to avoid. A common belief is that all man-in-the-loop models are high fidelity and very complicated, which is not necessarily the case. In one example recently used by a military contractor, aircraft, ships, and missiles are point masses with movements constrained by very simple tables or equations. Sensor capabilities are modeled by simple equations that are one step above cookie-cutters. Interactions with the environment, such as earth curvature and atmospheric attenuation on infrared sensors, are modeled equally simply. This example surfaced because of a deliberate attempt during requirements allocation on a specific project to emphasize human decision making rather than hardware modeling. It is a good example of breaking the traditional mold with an inexpensive alternative that fully satisfies study needs.

At the other extreme, lack of fidelity may also distort answers. Operations analysts have used a series of air-to-air combat models to answer questions about issues such as the value of increased thrust in fighter aircraft. The early versions of these models used cookie-cutter launch envelopes for the missiles with no provisions for infrared (IR) signature and missile-seeker effects. Head-on engagements with IR-guided missiles resulted in mutual kills. As a result, increased maximum thrust for close-in maneuvering combat on current generation aircraft like the F/A-18 or F-16 showed little improvement in expected kills and losses (two of the standard measures of effectiveness for combat aircraft). When moderately realistic IR features were introduced into the model, pilots were given the opportunity to reduce thrust in head-on situations and evaluate the results. Suddenly, the aircraft were spending about half of the engagement maneuvering in idle power to reduce the IR signature and increase survivability. Because there was much less time required to fly at maximum thrust to keep up aircraft energy (speed and altitude), the value of increased thrust over the shorter duration began to have a significant impact on the aircraft's effectiveness and survivability.

4.9.3.2.2 Use of Validated Tools

Validation dictates that **any** error incurred in the examination or study is within a tolerance band that ensures that results satisfy the expressed need to the agreed confidence level. **A validated analysis method or tool is defined as one that has been proven to provide credible results at the associated level of fidelity.** Validation may be performed using top-down or bottom-up techniques. Bottom-up validation is performed by comparing the methods and tool outputs, with varying sets of test case inputs, to the results of (1) another more complex validated model using the same test cases or (2) actual real world performance (i.e., telemetry gathered in an actual flight). Bottom-up validation via real-world performance is usually difficult because it is nearly impossible to determine the model inputs required to simulate the real-world system. Top-down validation ensures credibility by verifying the top-down structure and performance of individual components. The best choice for validation is top-down because the issues are better understood and there are fewer hidden assumptions.

For example, a software model that was previously validated to simulate a missile flight path without Global Positioning System (GPS) could be revalidated following the addition of a GPS receiver model in two ways:

1. **Bottom-Up Validation**. The overall results of the entire model (with the new software for GPS added) are compared to either another model or real world data.

2. **Top-Down Validation.** Only the new software component added to simulate the GPS receiver (i.e., by comparison to actual hardware) and its interface with the other previously validated software are validated.

Regardless of whether validation is top-down or bottoms-up, the algorithms and inputs used in the analysis tool shall be demonstrably correct and traceable back to their origin. It is a program management decision, and to what extent to use validated methods/tools. Examples of methods/tools that are candidates for formal validation include preflight modeling of unmanned aircraft/space vehicles, formal functional qualification testing, and Risk Management (Section 4.10). However, a significant amount of valuable analysis may be performed with unvalidated tools. Use of an unvalidated methodology/tool simply introduces the additional risk that the results may have reduced credibility. Often, this risk is acceptable when weighed against the inconvenience, increased cost, or inability to meet schedule associated with forcing the analyst to use a validated method/tool. In most cases, a new or modified tool initially is used without validation and a decision is made later regarding whether to perform validation based on expected future use of the tool.

4.9.3.2.3 Tool Validation Process

Authorized analysis methods and tools are used over a broad spectrum of applications. Analysis tool validation is specific to the analyzed system(s) and performance for which the toolset is demonstrated. Both applicability and use are defined for every case validation. Situations may occur in which analysis data is required to support the program before full toolset validation. To address these situations, provisional and limited validations have been identified. Both types of validations exist to satisfy program needs for analysis data in advance of full validation; however, neither invalidates the need for full validation.

a. **Full Tool Validation**. Tools are validated when they have met all accreditation requirements, have been recommended for validation by the responsible organization, and been reviewed by the Configuration Control Board (CCB) responsible for the baseline involved (Configuration Management (Section 4.11) provides more information on this topic).

b. **Provisional Tool Validation**. Provisional validation may be granted when model performance has been essentially demonstrated, but compliance with all validation requirements has not been achieved.

c. **Limited Tool Validation**. Tool validation may be limited to indicate that performance demonstration for full validation is incomplete, though all data indicate that model performance is correct and consistent for a limited analysis. Documentation requirements may be tailored for limited validation.

The analysis toolset validation process supports and is key to the analysis oversight responsibilities of each implementing program. Validation is based on demonstrating model performance, analyzing toolset configuration management/controls, and documenting the analysis methodology. As part of the approval process, the program manager designates approval authority for formal validation, which may be accomplished by forming an Analysis Review Board, or through the Program CCB, as discussed in Configuration Management (Section 4.11). If an Analysis Review Board is established, its membership may consist of program management, a member of SE, and a member of each project team using the analysis tools. The Program Board (Analysis or CCB) reviews applicability and use for which the analysis tool suite is to be validated. The term CCB is used for this board throughout the rest of this section.

Once the analysis method/toolset has been authorized for use, the implementing program determines whether the toolset requires validation for its usage and the degree of validation. The degree of validation required varies with the lifecycle stage and other factors. Methods of validation include verifying the ability of the tool to provide answers for known test cases or to cross-check the results with other tools or methods for agreement.

The tool validation portion of the AMP specifies what is to be tested, how it is to be tested, and what comparisons are to be made to reference check cases and other data in validating the analysis methods and tools. Reference check cases allow the responsible organization a comparative way to demonstrate that a toolset may be validated. It is recommended that comparison of analysis data to reference check case data be included as the first step in any validation plan. To complete validation, the responsible organization may propose any cost effective combination of the following methodologies listed in order of decreasing priority:

- Comparison of data with the real system
- Comparison to other analysis applications whose validation basis is actual test comparison
- Comparison of data with other validated toolsets
- Technical audit of toolset performance
- Demonstration of toolset capability

It is recommended that a sensitivity analysis be performed to characterize the behavior as each input is individually varied. The purpose for which the toolset is being validated is the primary concern in determining the mix of methodologies selected for validation.

Demonstrated performance refers to the ability of an analysis to produce results that compare favorably with results obtained from the system being modeled over common areas of performance. The responsible organization proposes its performance demonstration as part of the AMP. The overall demonstration shall be controlled by a matrix that has analysis capabilities/characteristics on one-axis and test scenarios (demonstrations) on the other axis. This matrix identifies how each analysis capability/characteristic is to be demonstrated for the purpose of certification. Once all performance demonstrations have been completed and action items assigned to the responsible organization(s) are closed, the CCB reviews the toolset validation package for completeness and assesses the need for further review before approving the validation package. In addition, a validation test matrix, which provides the CCB with a guide to validation requirements and completion status, is developed by the responsible organization. This test matrix is provided as part of the validation plan and is used by the CCB at subsequent review meetings to track validation completion status.

4.9.3.2.3.1 Validation Approval Package

The final validation package shall conform to the approved AMP. Approval of the following documentation is required as part of the Analysis toolset validation process:

a. AMP

b. Configuration Control Plan sections related to analysis toolset control

c. Analysis certification report

d. Analysis tool users manual

e. Analysis tool version definition

A member of the responsible organization presents the validation package to the CCB for final approval. Once the package has been approved, the responsible organization is provided with a signed validation certificate.

4.9.3.2.4 Validated Methods and Tool Configuration Management

The responsible organization maintains Configuration Management (Section 4.11) and controls the validated set of tools. All validated methods and tools are under configuration control and are documented in the approved Program Analysis Management and Configuration Management plans. Validated tool Configuration Management shall ensure traceability of all changes to validated tools over time, identification of the specific versions of the toolset used to develop analysis results, and the specific configuration of embedded hardware/software subsystems or components being modeled.

4.9.3.2.4.1 Criteria for Analytical Tool Validation Update

Changes within the analysis toolset that do not introduce changes to modeled systems or their performance domain do not require a validation update as long as regression testing demonstrates identical results. The responsible CCB defines specific validation update requirements for each analysis toolset as part of the review. The following guidelines are used to determine if validation update is required:

- If the analysis tool revision creates significant differences in analysis results, applicability, or use

- If there is significant program visibility and community interest in a functional characteristic which was modified

- If there are significant hardware/component changes to the systems being addressed that impact reference models, databases, or simulations

- If change accumulations account for a significant deviation from the previously validated baseline

If required changes impact more than one tool or model, the responsible CCB may ensure that all affected tools/models are appropriately revised and that changes installed continue to provide comparable analysis results. In every case, the responsible CCB may reassess the applicability to determine if the changes are required.

4.9.3.2.5 Analysis Reference Standards System

Analysis results are not expected to precisely replicate results from the modeled system(s). Additionally, analysis results may not be consistent among themselves. Analyses are compared to a standard reference set of baselines to ensure consistency of results when they are used to substantiate and evaluate specific areas of system performance. Only reference analyses, reference models, and reference databases are employed as performance or design baselines.

4.9.3.2.5.1 Reference Analyses

A set of authorized, validated analyses (certified in the case of simulations) is established as reference analysis methods. Accreditation of reference methods usually includes validation using actual test data. Reference simulations serve as the principal performance baseline(s) for the appropriate CCB action and provide a point of departure for derived analyses that may be used to establish the effect of proposed system design changes or to assess system sensitivities. Reference analysis methods typically include reference models and/or databases and are used to generate reference checkcases.

4.9.3.2.5.2 Reference Models

In cases where overlap exists between elements being modeled by more than one validated tool, the function modeled in one particular validated tool is identified by the CCB as a reference model. Reference models are established to capitalize on primary expertise in specific areas of performance and to provide consistency at the subsystem level. Reference models shall be segregated, validated, and made available to the analysis community.

4.9.3.2.5.3 Reference Databases

Reference databases are established in cases where there is no advantage to modeling a subsystem function. Reference databases are created by a model that is used to generate tables of values that constitute the database. The database then represents the selected subsystem performance through tabulated values. Reference databases are established by the responsible CCB to provide consistency at the subsystem level, take maximum advantage of specific areas of expertise, and simplify analyses.

4.9.3.2.5.4 Reference Checkcases

Reference checkcases are selected, reviewed, and distributed to each CCB and are available to the responsible organizations as the basis for certification comparison. Reference checkcases are generated by reference analysis methods, often are based on actual test events, and include relevant inputs, initial conditions, assumptions, and expected outputs in a form (e.g., hard copy and/or electronic media) usable by each responsible organization.

4.9.3.3 Task 3: Ensure Analysts Have Appropriate Skill Set

The previous paragraphs on using the right tools addressed the level of confidence required for each analysis, as stated in the AMP. Part of that confidence, from a programmatic sense, is derived from the proficiency of the analyst. Quantification of that component of confidence may be difficult or impossible to precisely determine, but qualitatively it shall be addressed. There are three elements involved:

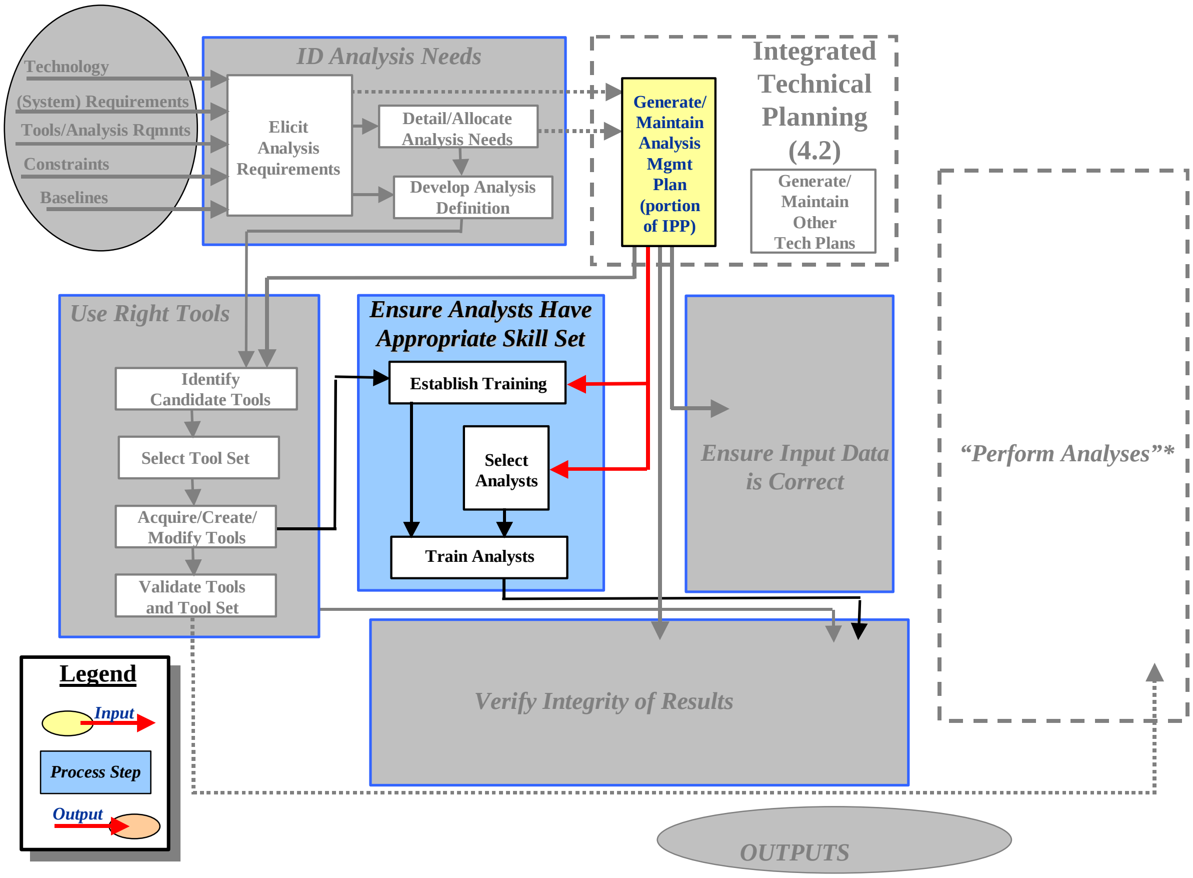

Figure 4.9-6. Ensure Analysts Have Appropriate Skill Set

(1) establish the training required, (2) select the analyst(s), and (3) train the analyst(s) based on a gap analysis between the skill set required to perform the analysis and the skills the analyst already possesses.

The AMP shall describe the approach to be used for each analysis to ensure that the analyst possesses the necessary level of proficiency to perform the analysis. Such approaches include:

- Acceptance of credentials (e.g., validated professional degrees, personnel performance reviews, known track record) or stipulation by supervisors. The currency of such information is important—this aspect is addressed in the "Establish Training" element.

- Training accomplished within a defined previous period (and whether subsequent test or demonstration of performance validated such training). In the sense of on-the-job training, a policy of ongoing revalidation of analysts is useful, if for no other reason than to maintain a current roster of analysts and their credentials.

- Satisfactory performance in a validation trial to be judged against prescribed target results.

An extreme case, in which the program may be at great risk unless a particular analysis has a very high confidence, may lead to the need to: (1) to certify analysts as world-class experts in using a particular version of the tool to be used; (2) ensure that the experts have recent experience in its use in a very similar application; and (3) require a number of identical but independent analyses by different but independent analysts to produce results within a specified tolerance of each other, or against a reference case or test data. An example would be the thermal analyses that were required early in the International Space Station program that were necessitated by a proposed change in orbit inclination coupled with a major change in assembly sequence in orbit.

For the purposes of this manual, programmatic issues as well as purely technical issues are included. Consequently, it is appropriate to discuss the distinction between competence and proficiency. Competence deals with one's ability to achieve excellence in results, no matter how much it takes. Analysts may be distinguished on the basis of the ease, speed, and/or clarity with which their results are produced. No guidelines are offered herein, but it is recommended that the matter be addressed in the AMP.

Another evaluation method is the technique of "peer review." The practice of using a nearby colleague (typically of approximately the same competence) to review the analysis has been shown to be useful. In analytic work, the opportunities for simple neglect or even typographical errors are great, and it is impossible to easily detect personal errors; however, with peer review, these kind of problems are more easily found. An analyst may believe himself/herself capable of a certain job (and credentials may imply that), but peers may discover that his/her sphere of expertise does not include the analysis in question. (The most dangerous situation is often when one does not realize what he/she does not know.) The AMP documents the implementation of program management's policies in this area. This process task appears in Figure 4.9-6.

4.9.3.4 Task 4: Ensure Input Data Is Correct

It is ultimately an analyst's responsibility to determine that the data used in an analysis is appropriate for that analysis. This responsibility then flows upward in a program and organization, and the AMP addresses how that member's responsibility shall be supported. Special attention shall be paid to instances where analyses need to be merged or where one analysis provides input data for use in subsequent analyses. In such cases, it is especially necessary for analysts to use compatible data that agree in quality and type. The considerations involved are shown in Figure 4.9-7.

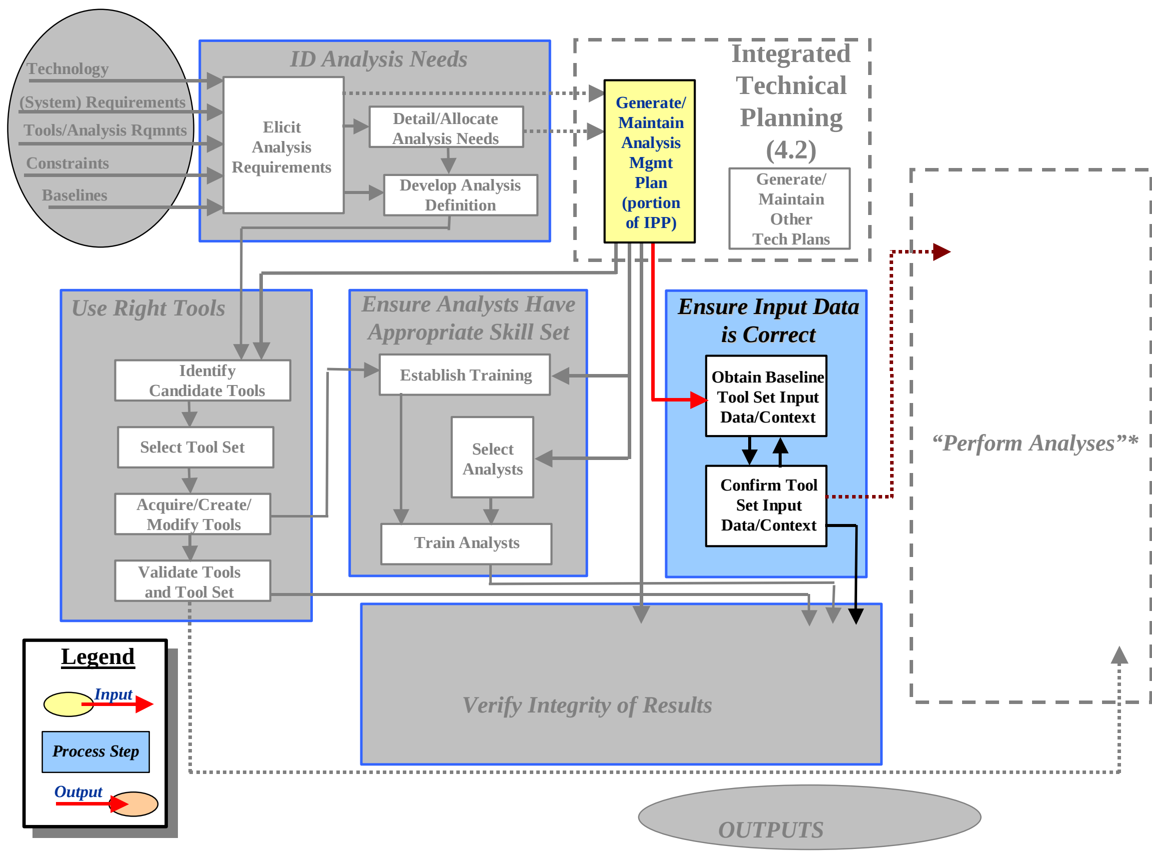

Figure 4.9-7. Ensure Input Data Is Correct

4.9.3.4.1 Data Sources and Control

The AMP specifies acceptable sources for each **kind** of data: general or universal data (such as atmospheric properties); corporate data (possibly proprietary, such as material properties or design limits); and program-specific data (tradeoff factors such as the partial derivative of aircraft range with respect to takeoff weight for a nominal mission). Organizational standards and libraries may exist that may be referenced, and a program may supplement those with program-unique data or define its own. The object is to provide baselined data and configuration control of that baseline by the process defined in the program plan. Using baselined data results in traceable analytic results. The consistency derived from all analysts using the same baselined data produces results may be confidently merged, compared, and/or interpreted. Besides the issue of where the data physically resides and from where it may be retrieved, there is the need to document and control the identification of the data's original source. If it represents measured data, its measurement error, range of uncertainty, or confidence interval shall be recorded.

4.9.3.4.2 Data Quality

One factor that shall be determined for each planned analysis is the **numerical confidence interval** that is acceptable in the results, which, in turn leads to a requirement for precision, accuracy, and granularity of the input data, as well as its treatment within the algorithms. Note that granularity includes the effect of decisions regarding the number of significant digits to be used. (There is no difference between declaring Pi to be 3.14 and defining it as the ratio of a circle's circumference to its diameter if both are measured to 3 significant digits.) Where the scope, required level of precision, or coarseness of an analysis calls for it, the AMP shall specify how baselined data may be approximated or granulized.

4.9.3.4.3 Documentation of Data within Analyses

An analysis is ultimately credible if it is able to be independently repeated. When repeatability is considered, it is clear that part of that ability is knowing exactly what data was used to create the first result; therefore, that data shall be carefully documented. The source, pedigree of validation, and extent of accuracy, precision, and granularity shall be documented, and the reader shall have the confidence that **all** the data were considered, even constants and parameters that are frequently forgotten, especially if they may have been **"**hard-coded**"** within a relation or equation.

4.9.3.5 Task 5: Perform Analysis

The actual analyses performed are described in the other sections of this manual. The Integrity of Analysis process supports the other SE processes and is intended to provide a disciplined framework for conducting any required analysis, whether technical, programmatic, or administrative in nature. The interaction between the Integrity of Analysis process and the actual performance of analyses appears in Figure 4.9-8

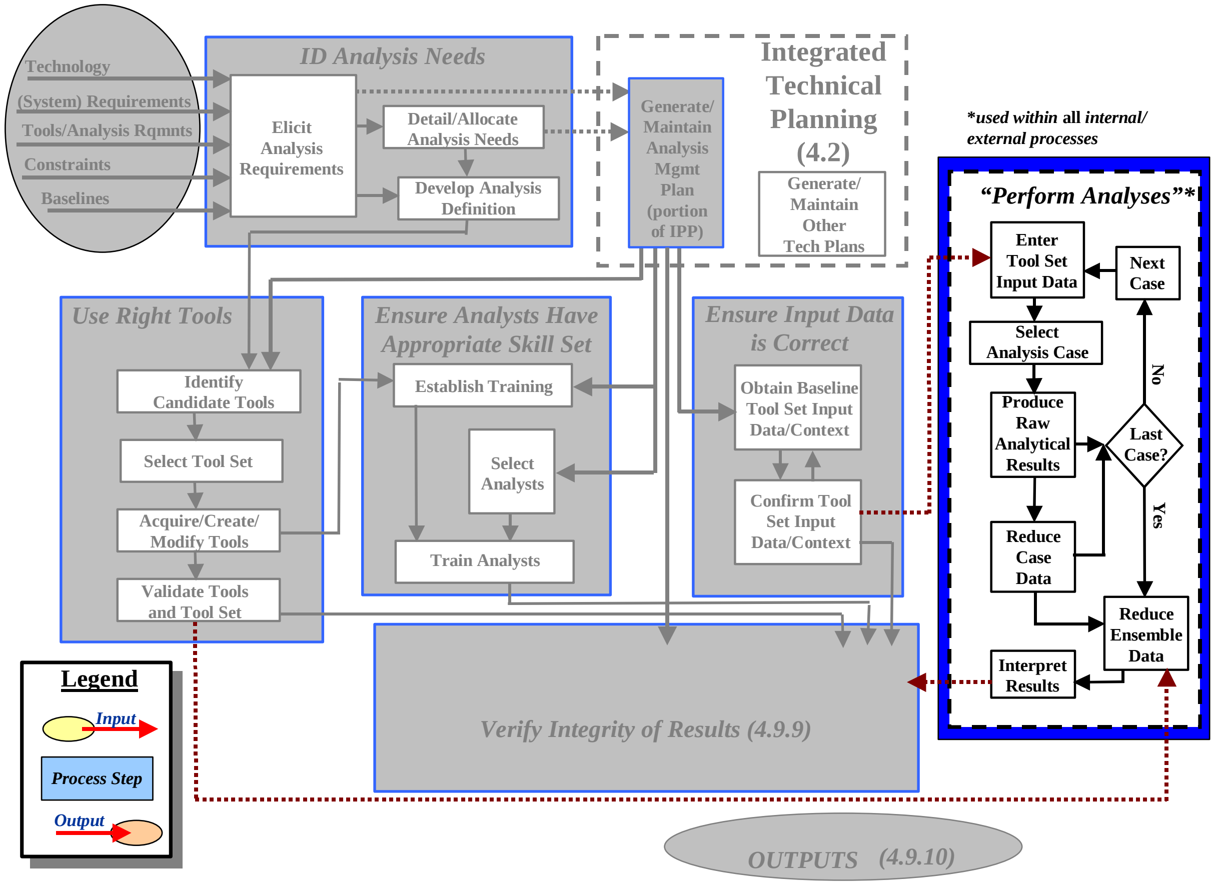

Figure 4.9-8. Perform Analyses Reference

4.9.3.6 Task 6: Verify Integrity of Results

In general, an analysis is useless unless it may be independently repeated; therefore, the inputs and all underlying assumptions shall be documented. It is recommended that criteria be established in the AMP for each type of analysis to ensure that the results are accurate, correct, and sufficient. The criteria are enforced by developing, validating, and using analysis templates. Comparing results from two or more truly independent analyses may be performed to achieve confidence in the results when the accuracy and/or validity of the analysis tools and methods have not been proven. The greater the independence of the individual analyses, the greater the confidence in the validity of the result.

Sufficiency of the analysis shall also be addressed: Did the analysis consider the entire envelope of interest? Were the selected portions of the envelope adequate to draw a proper conclusion? Did the analysis account for all significant effects? In rare cases, it may be necessary to perform an analysis to determine precisely which effects need to be considered to substantiate the results of an analysis.

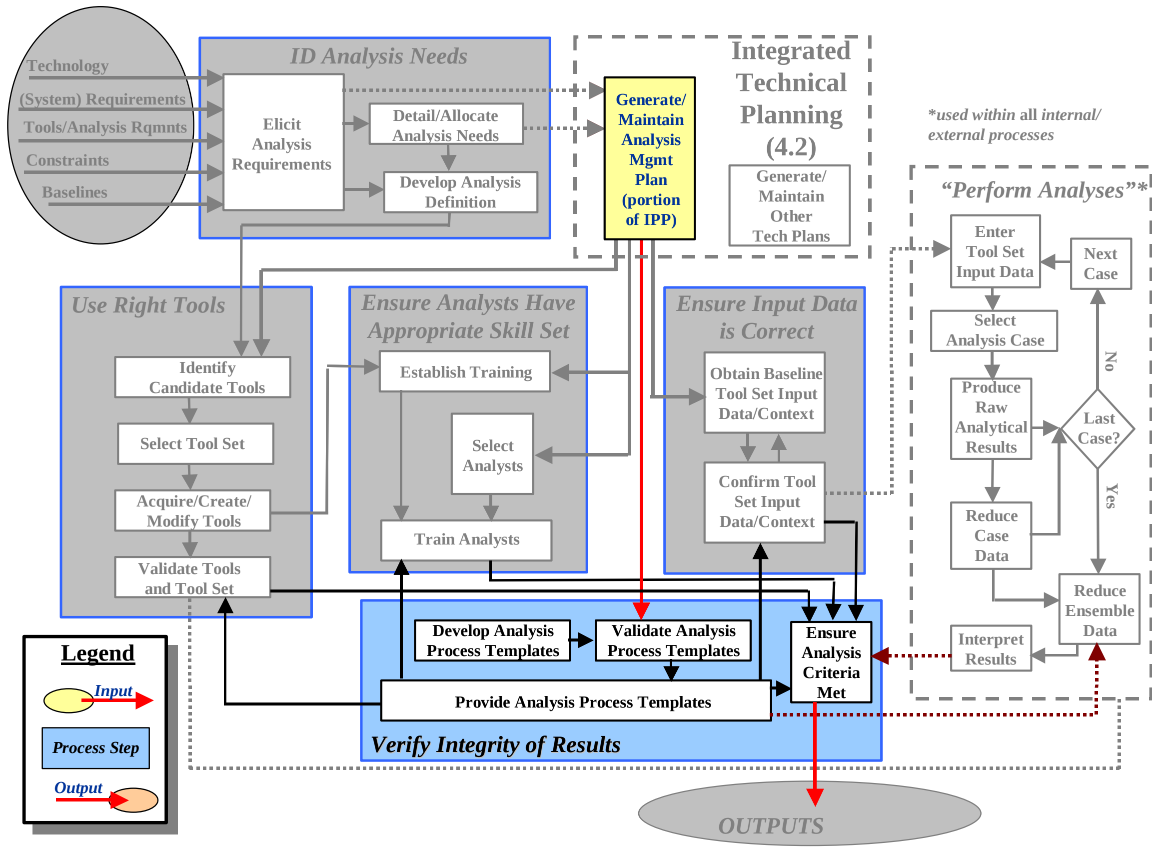

Figure 4.9-9. Verify Integrity of Results

- Even though a modeling technique or simulation tool has been proven to be completely accurate, errors may still be present in an analysis. Errors in an analysis may be caused by omitting terms that have a significant effect on the result, using the wrong input data (e.g., wrong atmospheric model), and misinterpreting/misunderstanding input data (e.g., wrong units, wrong reference coordinate system). Independent analysis may catch these errors only if there is no collaboration between the analysts. The criticality of the results of the analysis should determine the degree of verification justified.

- Another type of innocent error is caused by an analyst's misunderstanding of the problem statement (i.e., requirements). In this case, a completely valid answer may be presented to the wrong question.

- An analysis may be nothing more than an opinion poll. Evaluating the characteristics of the population considered only ensures this accuracy of this type of analysis.

- Ultimately, the results are verified by users per the original plan. If the results are insufficient, then a root cause analysis is performed where appropriate. The outcome of this analysis may result in the original analysis being reconducted by modifying:
  - Methods
  - Tools

– Inputs
– Users

4.9.4 Outputs of Integrity of Analyses

The two major outputs of this process are analysis criteria captured in the AMP and credible analysis results (Figure 4.9-10). In addition, any residual issues/concerns generated by this process are furnished to the Risk Management process (Section 4.10) for resolution. Any constraints driven by tool selection, skill requirements, or other programmatic considerations documented in the AMP are furnished to the Trade Studies process (Section 4.6) to assist in defining the appropriate trade space.

4.9.4.1 Analysis Criteria

The AMP is used to specify the analysis philosophy to be imposed. It is recommended that every analysis be understood as being bounded or constrained by all the pressures implied above. It is important to capture these issues in the AMP so that aspects such as the following are treated in the plan

The degree of validation required for each tool and type of analysis shall be specified. Tools as simple as an Excel spreadsheet or as complex as man-in-the loop simulations may be used to support programmatic decisions. A method shall be developed to verify that the correct equations are used for the analysis and that they have been properly implemented in the spreadsheet. Whatever the tool, the plan specifies the procedure for acquiring/developing, maintaining, and validating that tool. Typically, a program has a configuration control function (its own, or some core organization's) from which validated tool lists may be drawn and referenced.

- Methods shall be specified to ensure that analysts are proficient in using the tools and executing the analyses. This consists of providing proper documentation, training, and review procedures.

- Methods and analysis criteria shall be specified to ensure that data of the proper quality and range, from documented sources with valid pedigrees, are under configuration control and, thus, traceable when referenced by the analysis documentation.

- The required level of documentation for each type of analysis shall be specified, usually in the form of templates. Formal analysis shall provide sufficient documentation to permit reconstruction of the results from the input data. Quick analysis used to rule out a possible system design may not require the level of documentation or substantiation as analyses that are required to support the final system configuration.

- The review policy for each type of analysis shall be specified.

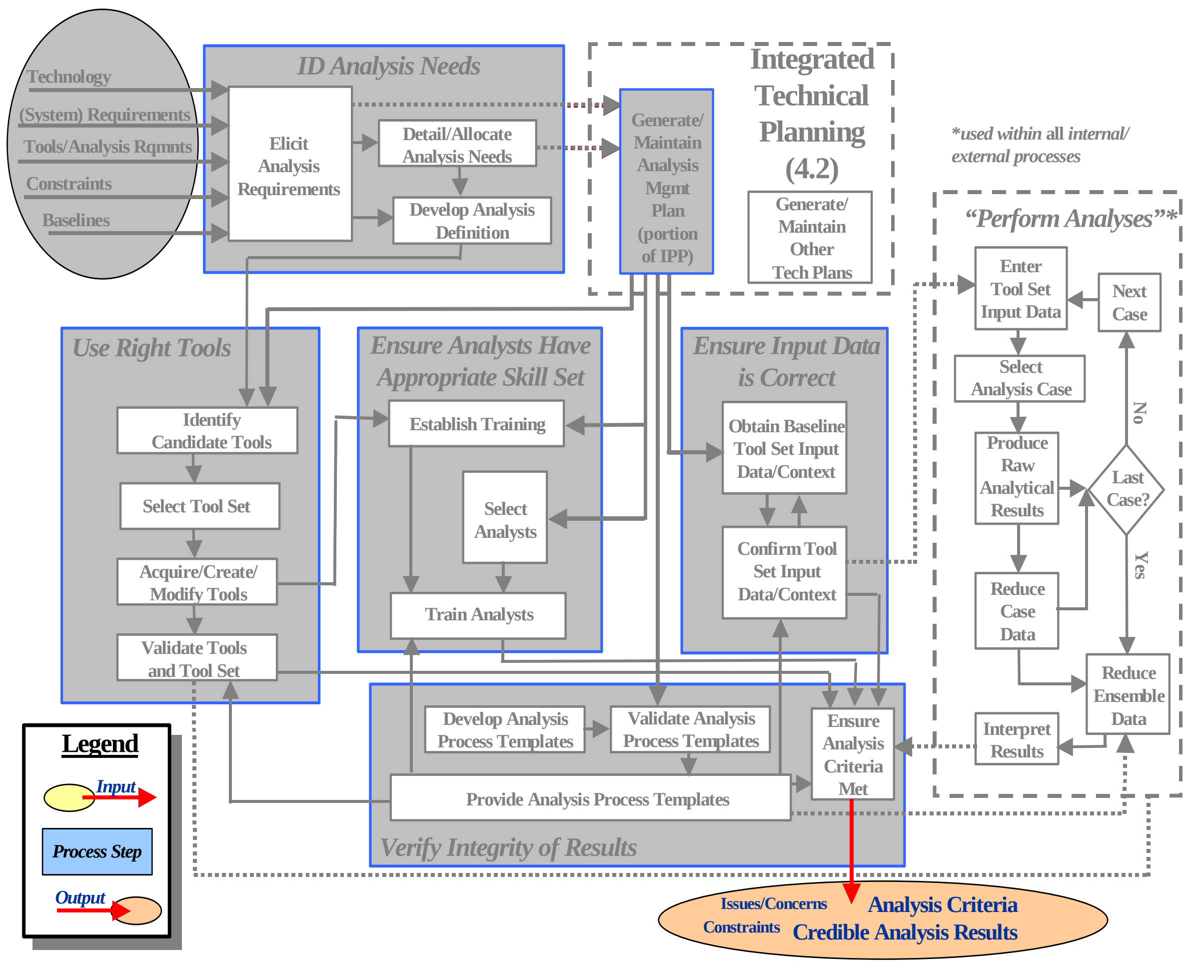

Figure 4.9-10. Integrity of Analyses Outputs

4.9.4.2 Credible Analysis Results

Simulated results are not expected to precisely replicate results from the simulated systems. Additionally, analysis results may not be consistent among themselves. Models shall be compared to standard reference baselines to ensure consistency of results when employed to substantiate and evaluate specific areas of system performance. Only reference simulations, reference models, and reference databases may be employed as performance or design baselines. Analysis results are meaningless without description of the analysis method and the assumptions that generated those results. If the tool version used to generate the results is not validated, the differences between the validated version and the version used, as well as the validation plans for the new version, are also to be presented.

4.9.5 Integrity of Analyses Process Metrics

There are four general measurement categories that are applicable to Integrity of Analyses, and they are shown in Table 4.9.1, along with candidate measures for analysis management. It is recommended that each effort tailor these measures and add other project-specific measures that are applicable to ensure that they contribute the necessary information to the decision-making processes.

Table 4.9-1. Integrity of Analyses Measurement Categories

Schedule and Progress	Resources and Cost	Product Quality	Process Performance
Percent of analysis tasks completed on schedule	Existing validated model is ratio of analysis to total hours **(Total** = analysis hours + verification hours.)	Percent of analysis "passing" verification step (first pass)	Average number of days to complete analysis (per same tool and complexity).

Example of common issue areas, measurement categories, and sample measures.

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